AI-Assisted Knowledge-Defined Multilayer Optical Networks

Zuqing Zhu†, Siqi Liu, Baojia Li, Wei Lu
School of Information Science and Technology, University of Science and Technology of China, Hefei, China
†Email: {zqzhu}@ieee.org

***Abstract*—We discuss the system design to realize artificial intelligence assisted knowledge-defined cross-layer orchestration in IP over elastic optical networks. Deep learning is introduced in the control plane (CP) for traffic analysis and prediction, and consistently provides suggestions to the CP for achieving future-friendly traffic routing.**

***Index Terms*—Multilayer optical networks, IP over optical, Elastic optical networks (EONs), Deep learning, Knowledge-defined networking (KDN), Artificial intelligence (AI).**

I. Introduction

Recently, with the fast development of cloud computing, Big Data and social networks, the Internet is facing unprecedented growth of IP traffic [1]. This stimulated intensive researches on scalable, flexible and application-aware optical networking technologies [2]. However, it is known that traditional wavelength-division multiplexing (WDM) networks are restricted by the fixed-grids and thus can hardly realize adaptive bandwidth allocation and enhanced spectrum efficiency in the optical layer [3, 4]. Fortunately, the bottleneck can be properly addressed by introducing the flexible-grid elastic optical networks [5–7]. By leveraging bandwidth-variable transponders (BV-Ts) and bandwidth-variable wavelength-selective switches (BV-WSS') [8], EONs achieve finer bandwidth allocation granularity and can customize the channel sizes of lightpaths much more flexibly. Although EONs are more flexible, adaptive and application-aware than WDM networks, they still use circuit switching. Therefore, to seamlessly support the ever-growing IP-based Internet applications, the operators need an IP layer based on packet switching to provision their services cost-effectively, which suggests that a rational combination of IP and EON technologies would be inevitable [9].

In an IP-over-EON, the EON serves as the underlying optical transport layer to provide lightpaths as the high-speed data transmission channels, while the IP network sitting on top of it switches packets among the lightpaths to facilitate efficient resource allocation for carrying highly dynamic application traffic. Note that, due to the enhanced flexibility and adaptivity, the network control and management (NC&M) mechanism in such a multilayer IP-over-EON needs to handle more complicated tasks than those in a traditional IP-over-WDM network. More importantly, treating the IP and EON layers separately might not leads to the optimal solution in an IP-over-EON. For instance, it is known that the traffic loss due to IP router outages can hardly be recovered timely and efficiently with the restoration schemes solely in the IP layer or the EON layer [9, 10]. This actually motivates people to design effective cross-layer orchestration mechanisms for IP-over-EONs based on software-defined networking (SDN). Specifically, the applications of SDN in EONs have already indicated that the centralized NC&M can respond quickly to manage various tasks effectively [11].

In this paper, we discuss how to realize artificial intelligence (AI) assisted knowledge-defined cross-layer orchestration in IP-over-EONs, based on the idea of software-defined IP-over-EON (SD-IPoEON). Section II explains why the existing cross-layer orchestration mechanisms, which manage a multilayer optical network only based on the current network status, might not always be effective, and introduces the idea of adding a deep learning (DL) module into the control plane to analyze traffic proactively and handle future congestions and failures effectively. The system design and operation principle of the AI-assisted SD-IPoEON are described in Section III. Finally, Section IV summarizes the paper.

II. Knowledge-Defined Cross-Layer Orchestration

Note that, most of the existing NC&M mechanisms manage a multilayer optical network only based on the current network status or the explicit data plane (DP) information that is available to the control plane (CP). However, this is not good enough since IP traffic is usually highly dynamic and bursty. Hence, even though the IP traffic grooming scheme based on the current network status may use the lightpaths in the EON efficiently, congestions or under-utilizations can happen in the future due to the sudden increase/decrease of certain flows' data-rates [12]. The issue can be resolved by leveraging the idea of knowledge-defined networking (KDN) [13] and adding a DL module into the CP for proactive traffic analysis. Specifically, the DL module takes historical traffic statistics as the input, trains itself for precise traffic prediction, and consistently provides suggestions to the CP for cross-layer traffic routing. Then, the CP can obtain the most effective routing schemes for IP traffic flows based on the current and predicted network status, and respond to changes timely.

III. System Design and Operation Principle

Fig. 1 shows the proposed architecture for the AI-assisted SD-IPoEON. Here, the IP layer in the DP is built based on OpenFlow switches (OF-SWs) that are equipped with optical ports. The EON layer uses BV-WSS' to interconnect the

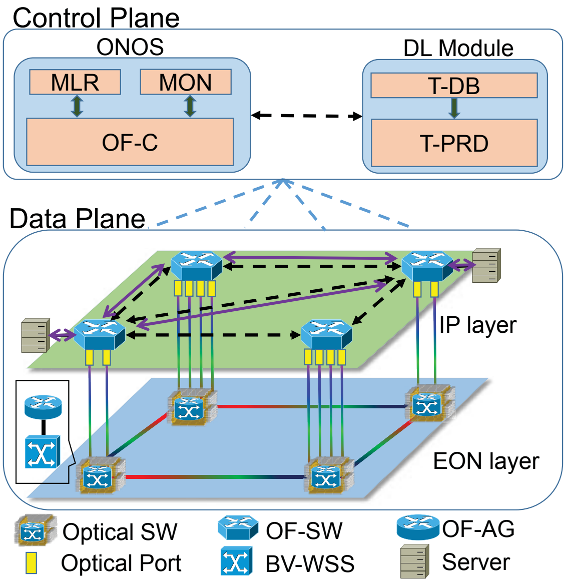

Fig. 1. Network architecture of software-defined IP-over-EON (SD-IPoEON), MLR: multilayer restoration module, MON: monitoring module, OF-C: OpenFlow controller, DL Module: deep learning module, T-DB: traffic database, T-PRD: traffic predictor, Optical SW: optical switch, OF-SW: OpenFlow switch, OF-AG: OpenFlow agent, BV-WSS: bandwidth-variable wavelength selective switch (adapted from [12]).

optical ports with lightpaths. Therefore, two clients in the IP layer can communicate with each other either through an end-to-end lightpath directly, or multiple lightpaths that conduct traffic de-/re-grooming at intermediate OF-SW(s). The actual communication scheme is determined and implemented by the CP, which consists of an ONOS module [14] and a DL module. The OpenFlow controller (OF-C) in the ONOS talks with the network elements in the DP (*e.g.*, OF-SWs and BV-WSS') to realize cross-layer orchestration. More specifically, the OF-C sends flow-tables to the OF-SWs for traffic de-/re-grooming, and in the meantime, it instructs the OpenFlow agents (OF-AGs) [15, 16] on the BV-WSS' to realizing lightpath setup/removal. We also implement a monitoring module (MON) in the ONOS to observe the status of each network element in the DP and collect traffic statistics periodically. As network survivability is very important in optical networks [17], we implement a multilayer restoration module (MLR) in the ONOS to calculate the rerouting schemes for affected flows in case of network failures.

The DL receives the traffic statistics collected by the MON consistently, and it stores them in the traffic database (T-DB). The stored traffic statistics are utilized to train the traffic predictor (T-PRD), which is based on a long short-term memory neural network (LSTM-NN) [18]. Specifically, the T-PRD takes historical traffic statistics as inputs and can forecast future traffic variations precisely after proper training. The DL module is implemented based on TensorFlow. Therefore, when a network status change is detected by the MON, the CP achieves AI-assisted cross-layer orchestration by letting ONOS calculate the most effective routing schemes for IP flows based on the traffic prediction provided by the DL module. Then, the routing schemes are implemented in the DP for future-proof NC&M. To this end, we can see that our proposal reveals a promising use-case of KDN in IP-over-EONs.

IV. Conclusion

We designed an SD-IPoEON system, which can realize AI-assisted cross-layer orchestration and achieve future-friendly IP traffic routing based on the precise traffic predication from a DL module, to improve the network's cost-effectiveness.

Acknowledgments

This work was supported in part by the NSFC Projects 61701472 and 61771445, CAS Key Project (QYZDY-SSW-JSC003), NGBWMCN Key Project (2017ZX03001019-004), China Postdoctoral Science Foundation (2016M602031), and Research Funds for Central Universities (WK2100060021).

References

[1] "Cisco global cloud index: Forecast and methodology, 2016-2021," 2017, [Online]. Available: https://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html.

[2] P. Lu *et al.*, "Highly-efficient data migration and backup for big data applications in elastic optical inter-datacenter networks," *IEEE Netw.*, vol. 29, pp. 36–42, Sept./Oct. 2015.

[3] O. Gerstel, M. Jinno, A. Lord, and B. Yoo, "Elastic optical networking: a new dawn for the optical layer?" *IEEE Commun. Mag.*, vol. 50, pp. S12–S20, Apr. 2012.

[4] Z. Zhu, W. Lu, L. Zhang, and N. Ansari, "Dynamic service provisioning in elastic optical networks with hybrid single-/multi-path routing," *J. Lightw. Technol.*, vol. 31, pp. 15–22, Jan. 2013.

[5] L. Gong, X. Zhou, W. Lu, and Z. Zhu, "A two-population based evolutionary approach for optimizing routing, modulation and spectrum assignments (RMSA) in O-OFDM networks," *IEEE Commun. Lett.*, vol. 16, pp. 1520–1523, Sept. 2012.

[6] Y. Yin *et al.*, "Spectral and spatial 2D fragmentation-aware routing and spectrum assignment algorithms in elastic optical networks," *J. Opt. Commun. Netw.*, vol. 5, pp. A100–A106, Oct. 2013.

[7] L. Gong and Z. Zhu, "Virtual optical network embedding (VONE) over elastic optical networks," *J. Lightw. Technol.*, vol. 32, pp. 450–460, Feb. 2014.

[8] N. Sambo *et al.*, "Next generation sliceable bandwidth variable transponders," *IEEE Commu. Mag.*, vol. 53, pp. 163–171, Feb. 2015.

[9] S. Liu, W. Lu, and Z. Zhu, "On the cross-layer orchestration to address IP router outages with cost-efficient multilayer restoration in IP-over-EONs," *J. Opt. Commun. Netw.*, vol. 10, pp. A122–A132, Jan. 2018.

[10] W. Lu, X. Yin, X. Cheng, and Z. Zhu, "On cost-efficient integrated multilayer protection planning in IP-over-EONs," *J. Lightw. Technol., in Press*, 2018.

[11] Z. Zhu *et al.*, "OpenFlow-assisted online defragmentation in single-/multi-domain software-defined elastic optical networks," *J. Opt. Commun. Netw.*, vol. 7, pp. A7–A15, Jan. 2015.

[12] S. Liu, B. Li, and Z. Zhu, "Realizing AI-assisted multi-layer restoration in a software-defined IP-over-EON with deep learning: An experimental study," in *Proc. of OFC 2018*, pp. 1–3, Mar. 2018.

[13] A. Mestres *et al.*, "Knowledge-defined networking," *ACM SIGCOMM Comput. Commun. Rev.*, vol. 47, pp. 2–10, Jul. 2017.

[14] Open Network Operating System (ONOS). [Online]. Available: http://onosproject.org/

[15] C. Chen *et al.*, "Demonstrations of efficient online spectrum defragmentation in software-defined elastic optical networks," *J. Lightw. Technol.*, vol. 32, pp. 4701–4711, Dec. 2014.

[16] Z. Zhu *et al.*, "Demonstration of cooperative resource allocation in an OpenFlow-controlled multidomain and multinational SD-EON testbed," *J. Lightw. Technol.*, vol. 33, pp. 1508–1514, Apr. 2015.

[17] F. Ji *et al.*, "Dynamic p-cycle protection in spectrum-sliced elastic optical networks," *J. Lightw. Technol.*, vol. 32, pp. 1190–1199, Mar. 2014.

[18] I. Goodfellow, Y. Bengio, and A. Courville, *Deep Learning*. MIT Press, 2016, http://www.deeplearningbook.org.